

Disclaimer

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CHAPTER 1 INTRODUCTION

This chapter presents an overview of pavement preservation and how Preventive Maintenance treatments can be used to preserve the condition of a highway system. It presents a discussion of various pavement distresses and identifies the potential causes for the observed distress types. Also discussed are the various treatment types used in Preventive Maintenance including the selection of the most appropriate treatment. These topics are discussed in greater detail in the subsequent Chapters 2 through 8.

The required characteristics of the various materials are defined in the Caltrans specifications and these describe the measurable properties that lead to the desired field performance. These include characteristics not only of the materials at the time of application, but also to achieve good in service field performance. Caltrans has a range of published specifications and these include "Standard Specifications" and "Standard Special Provisions" (SSP). They may be found on the Caltrans Web page http://www.dot.ca.gov/hq/esc/oe/specs_html/index.html.

This chapter covers the basics of pavement preservation and important aspects of the materials requirements for the maintenance treatments described in subsequent chapters. This chapter also includes some aspects of the mechanisms by which these materials perform their function and how they should be stored, handled, and combined to achieve the desired outcomes and meet the required specifications.

1.0 WHAT IS PAVEMENT PRESERVATION?

The development of pavement preservation is a relatively new practice in the US, but is beginning to pay dividends in many states. In many places, pavement preservation is termed "Preventive Maintenance". This implies an intervention in pavements, that is a treatment carried out, before distress has reached a level where the pavement's structural integrity has been compromised. "Corrective Maintenance" is a term used to describe actions required to restore pavement to a level where Preventive Maintenance or pavement preservation can be used to keep the pavement in a serviceable condition into the future. Definitions for the various terms used in this document are provided in Appendix A.

The principal requirements for Preventive Maintenance are:

- Is it part of an overall program of Caltrans pavement management system (PMS)?
- Has it been scheduled in the maintenance plan as determined by the PMS?
- Is it timely? Is it cost effective?
- Is it technically sound?
- Have expectations for the maintenance treatment been considered?

Figure 1 shows the relationship between pavement life (or in terms of traffic volume) and the type of treatment required to prolong the life of the pavement.

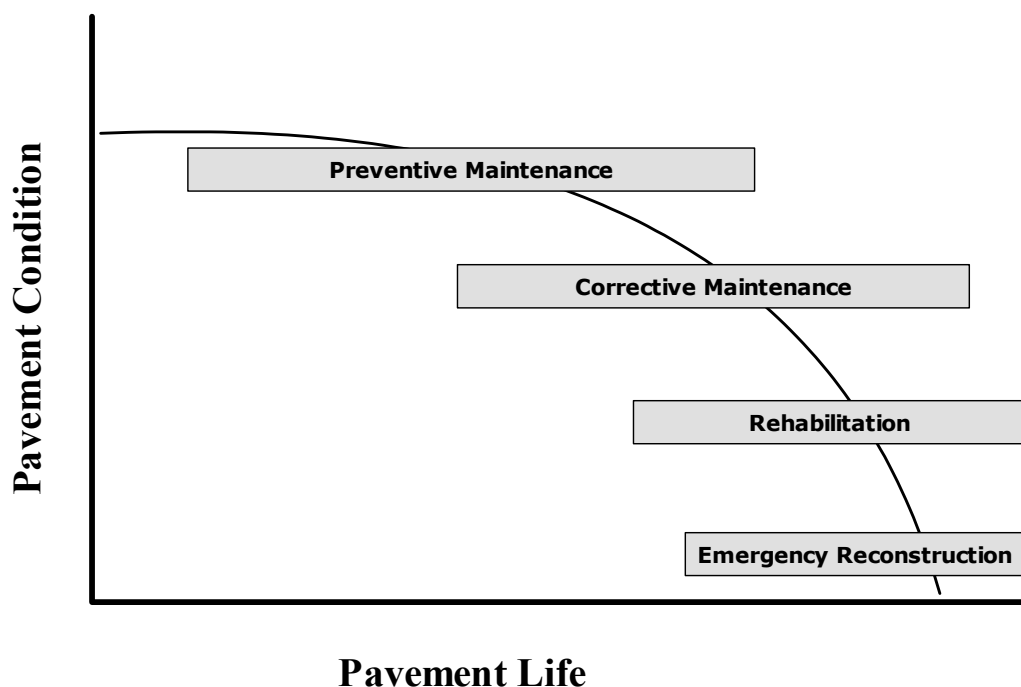


Figure 1: Pavement Condition vs. Life and Type of Work Required (1)

The timely application of preservation treatments is important as they can save money over the life of a pavement. Reconstruction or extensive dig-out and replacement treatments are far more costly than typical Preventive Maintenance treatments. Figure 2 shows the relative costs of Preventive Maintenance treatments versus major rehabilitation treatments or reconstruction. When properly timed, Preventive Maintenance can produce savings over the life of the pavement (1, 2). In addition, subsequent maintenance treatments can be applied in a relatively quick manner resulting in fewer disruptions to the traveling public and less exposure to traffic for maintenance employees as compared with major rehabilitation or reconstruction activities.

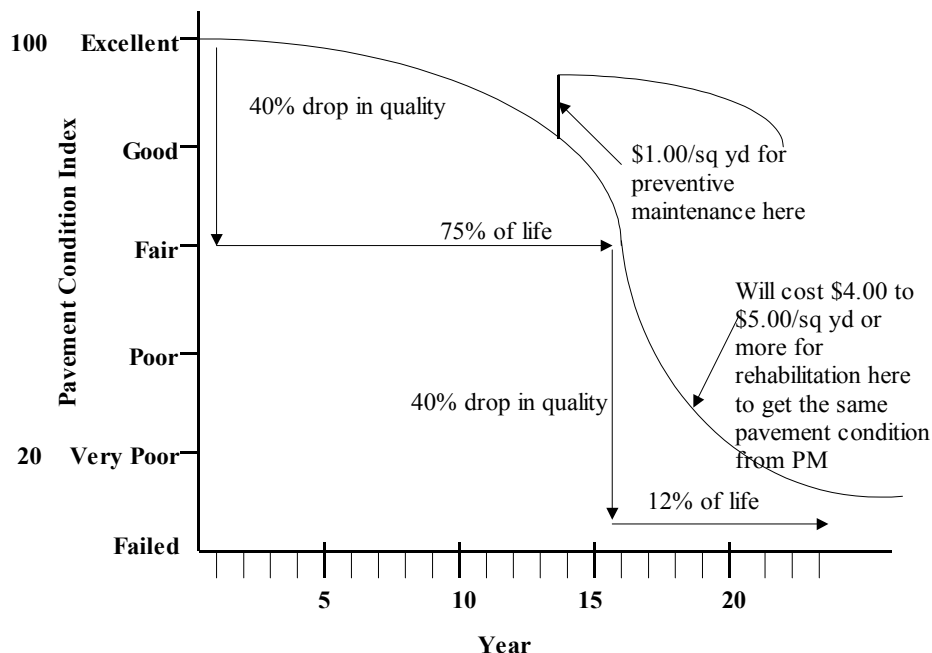


Figure 2: The Cost of NOT Carrying Out Maintenance in a Timely Way (2)

2.0 PAVEMENT STRUCTURE AND DESIGN

2.1 WHAT IS A PAVEMENT?

A pavement is a layer or layers of compacted material that is designed to withstand the stresses applied by vehicle or other traffic types and provide a smooth riding surface. Pavements are engineered structures by which stresses, applied from moving wheel loads, are transferred to the native soil (subgrade). Figures 3 and 4 illustrate conceptually the ways in which stress is applied to the roadway and how a pavement can reduce the stress applied to the subgrade. Cracking, deformation and disintegration are the main distress modes of pavements.

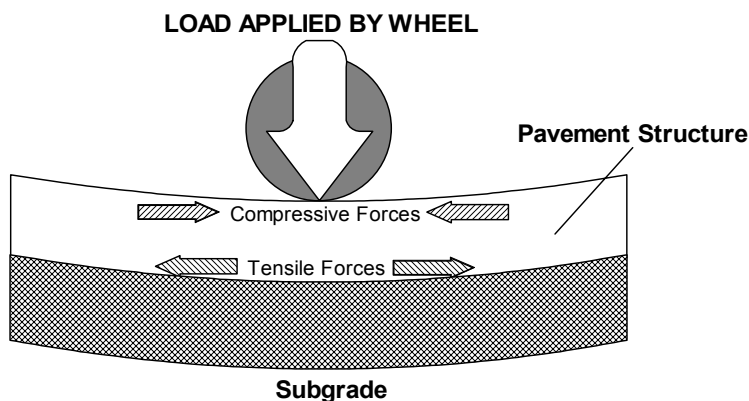


Figure 3: Stress in a Pavement from Wheel Loads (3)

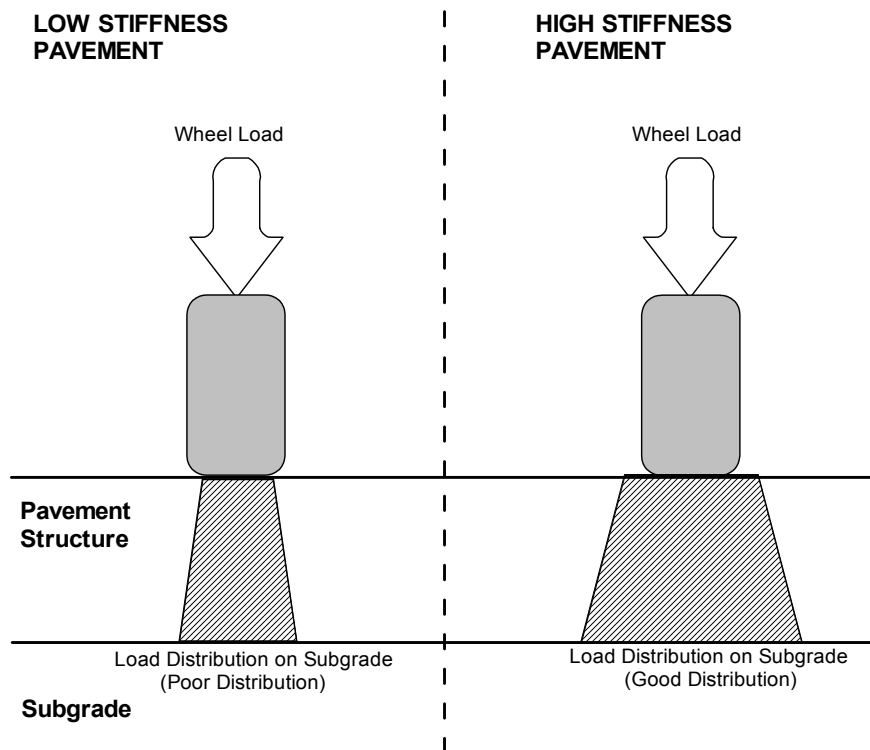


Figure 4: Load Spreading Effect on Subgrade (3)

2.2 FLEXIBLE AND RIGID PAVEMENTS

The pavement can be considered as the entire road structure. In this chapter, we are concerned primarily with the surface of the pavement, but the structural aspects of the remaining parts contribute greatly to the performance of any surfacing and must be understood.

The two main types of pavement in use in California are flexible and rigid pavements. The difference between the two is the manner in which they distribute the applied load to the subgrade. A rigid pavement (concrete), due to its high rigidity and high stiffness (modulus of elasticity) tends to distribute the loads over a wide area of subgrade; therefore, the slab itself carries the majority of the load. This is considered the major contributing factor to the performance of concrete pavements. This characteristic allows for minor variations in the subgrade strength, which have little effect on the structural capacity of the pavement. However, severe cracking problems can arise if the subgrade cannot support the slab.

Flexible pavements, on the other hand, consist of layers of granular materials and/or asphalt bound materials (such as hot mix asphalt or surfacing) with lower rigidity and stiffness as compared to rigid pavements. Such pavements generate their load bearing capacity based largely on the load distribution characteristics of the individual layers. The strength of a flexible pavement is built up using thick layers. These materials (layers) distribute the applied loads over the subgrade. As a result, the design thickness of the pavement is influenced by this load distribution mechanism and the strength of the subgrade. For these reasons, the material properties comprising each layer, their thickness, the subgrade strength, and the loading level are critical design parameters.

Pavement design is based on the structural analysis of multi-layered pavements subjected to traffic loading. A key to predicting performance is accurately modeling the stress and strain responses of the pavement and accounting for sub grade and environmental conditions affecting material properties.

2.3 PAVEMENT STRUCTURE

A pavement's structure can be broken down into three main components. Each component plays an important role in the overall performance of a pavement. These components are:

- Foundation
- Base
- Surfacing

Figure 5 shows typical pavement cross sections for both types of pavements.

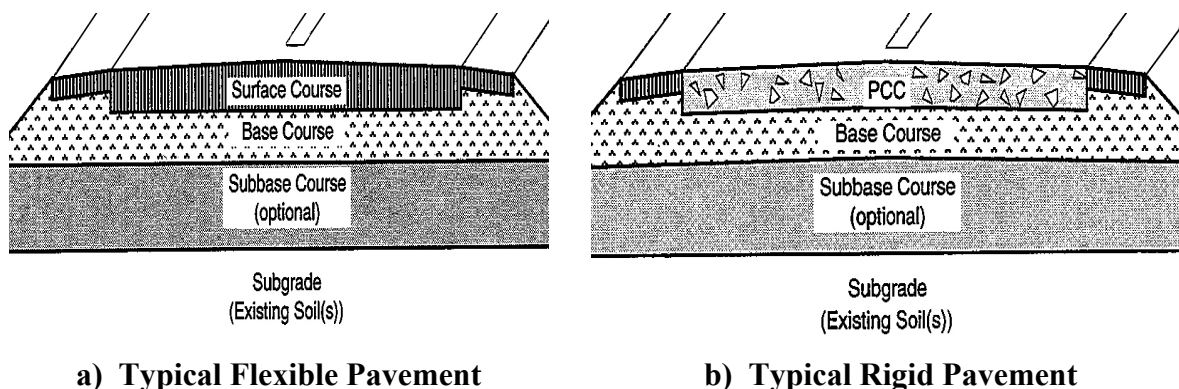


Figure 5: Typical Pavement Cross Sections (4)

2.3.1 Foundation

The foundation is comprised of the sub-grade and, in some cases, the sub-base. The foundation carries the loads created by construction traffic. Structurally, it is the final layer to which stress is transferred. As it is generally the weakest layer, stresses must be spread over as wide an area as possible. The foundation is characterized by its compressive strength or bearing capacity (e.g. in California using the "R" value).

2.3.2 Base Layer

The base layer is a main structural element of the design and can consist of several layers. It is required to spread the wheel load so that the foundation is not over-stressed. Its stiffness and its fatigue resistance (if stabilized) characterize its behavior in the pavement structure.

The base layer can consist of compacted high-grade aggregate, lean concrete, portland cement concrete or dense graded asphalt. In some areas, where drainage is poor or traffic is very heavy, a large stone mix with high voids can be used in the bottom part of this course. In situations where the subgrade is very weak, a binder rich layer may be used at the bottom of this course.

2.3.3 Surfacing Layer

The surfacing layer is provided to ensure adequate skid resistance and act as a protective layer for the underlying materials. It may or may not be structurally significant. Surfacing range from surface seals to thin hot mix overlays. If the surfacing is greater than 40mm (1.5 in) thick it will contribute to the structural integrity of the pavement, and must be considered in the design. The surface layer is where most rutting occurs. With this in mind, the design of this layer is very important.

Surface layers are characterized by their stiffness, creep resistance, moisture resistance, resistance to low temperature cracking, fatigue resistance and skid resistance. Figure 6 illustrates the main elements of the pavement structure with respect to the surfacing layer.

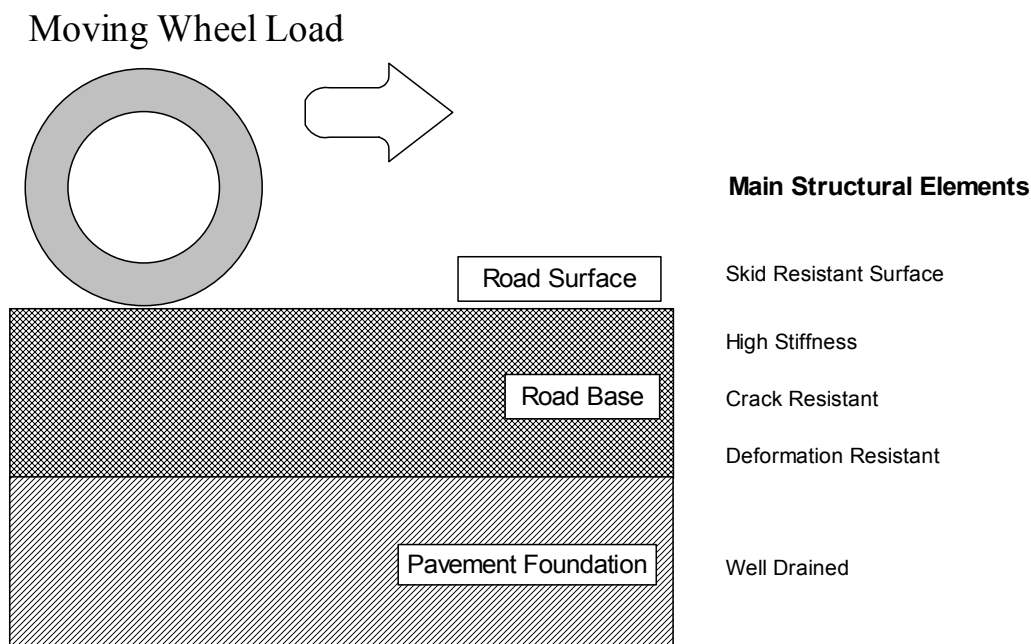


Figure 6: Elements of a Pavement Structure (3)

The integrity of the pavement structure is key to whether a road requires reconstruction, resurfacing or a maintenance treatment. The failure mode observed can be a structural failure or a surface failure. Structural failures can result from poor design, excess traffic volumes or weights, poor drainage, poor materials and/or poor construction practices. Structural failures may also be associated with poor bonding between the surface layer and the pavement which lead to slippage cracking.

Surface failures may look similar to those caused by structural failures but their causes are different. Surface failures result from aging, surface abrasion, poor design (inappropriate asphalt content), poor materials (weak aggregates), poor construction practices or inappropriate use of a treatment. It is important to identify the cause of a failure to allow the simplest and cost effective maintenance treatment to be used to solve the problem. It is very important to thoroughly evaluate and properly diagnose the cause of a failure; this will suggest the appropriate treatment. It is also important not to worsen a problem by applying an incorrect maintenance treatment.

In all cases, it is important to look at the real cause of failure and make adjustments in materials and practice, as well as future design, to reduce the frequency of such failures. A good pavement preservation or rehabilitation policy is a quality tool that when used properly can improve the entire pavement system.

The selection of the maintenance or rehabilitation treatment is a function of many factors including the pavement distress. In summary, the primary requirement of a treatment is to address the primary needs of the roadway. Once the needs for the roadway are determined, an appropriate treatment can be chosen that provides for the roadway needs. Table 1 provides a guide, based on the needs of the road users, to the appropriate surfacing characteristic.

Table 1: Surfacing Requirements (5)

ROAD USER REQUIREMENT AND SURFACE PROPERTIES	
ROAD USER REQUIREMENT	KEY PROPERTY OF SURFACE
Good low speed skid resistance	High polish resistant coarse aggregate
Good high speed skid resistance and prevention of hydroplaning	High polish resistant coarse aggregate and high surface texture
Visible road markings	High surface texture
Low spray generation	Porous surfacing (best) or high surface texture (high hydraulic conductivity)
Low glare and specular reflection	Sufficient surface texture
Low tire / road noise	Porous surfacing or low surface texture
Smooth ride	Smooth surface – thicker surfacing can reduce roughness in underlying layers
Low construction and maintenance costs	High durability surfacing, thin surfacing
Minimize delays during construction/maintenance	Durable surfacing (less frequent maintenance)
Minimum wear and tear on vehicle and load	Smooth surface – thicker surface can reduce roughness in underlying layers
No windshield breakage caused by construction operations	Use construction techniques that minimizes loose surface stones

3.0 COMMON DISTRESSES IN PAVEMENT STRUCTURES AND TYPICAL TREATMENTS

Pavement structures become distressed and deteriorate as a result of many factors. Common types of distress are discussed briefly in the following paragraphs while Chapters 3 through 8 provide more detailed information with regard to the appropriate level of distress for a given maintenance treatment.

3.1 DISTRESSES IN THE SUBSURFACE LAYERS

The distresses in the subgrade soil impact all layers above it. Distresses in the subgrade soil include excessive deflection, shear failures and consolidation, or settlement. Excessive deflection often results in areas of fatigue cracking in the surface layer of the pavement structure. Shear failures also occur on slopes often resulting in a large vertical displacement of the portion of the pavement surface located immediately above the distressed area.

Consolidation can occur over a large area resulting in the entire width of the pavement “sinking,” or it can occur in localized areas, particularly below the wheel paths, resulting in rutting.

Although many factors affect the strength of the granular materials that make-up the base and subbase layers, the size distribution of the aggregate (particularly the proportion of fine to coarse aggregate) is considered to be the most important. Materials that are very dirty (i.e., contain a substantial amount of fine-grained soil) have low strength characteristics and are susceptible to frost heave. Low strength in the base and/or subbase layer can cause a number of problems to the surface layer such as cracking, rutting, depressions, etc. Also, heave due to frost action can cause significant vertical displacement of the surface layer, often resulting in cracking.

3.2 DISTRESSES IN THE SURFACE LAYER

A number of distresses occur to the hot mix asphalt (HMA) surface layer of a pavement structure, but these can be broadly categorized as distresses associated with cracking, deformation, deterioration, and mat problems. Cracking can occur as a result of traffic loading, thermal stresses as a result of low temperatures or due to oxidation at the surface. Deformation (e.g., rutting, shoving, etc.) in the HMA layer is often caused by traffic loading at elevated temperatures. Deterioration of the surface (e.g., raveling, stripping, etc.) is caused by a variety of factors such as problems with the HMA materials, mix design problems, environmental conditions, and traffic loading. Finally, problems in the mat (e.g., segregated mix, bleeding) are typically caused by problems associated with mix design or improper construction techniques.

3.3 TYPICAL TREATMENTS

Treatment of distresses in the subsurface layers requires removal and replacement of at least the surface layer and, thus, such operations are more expensive than treatment of distresses in the surface layer. Correcting problems with the subsurface layers usually requires major rehabilitation or reconstruction. Correcting problems with the surface layer, on the other hand, can be preventive or corrective in nature (Figure 1) if performed before the surface layer degrades substantially. The treatments described in Chapters 3 through 8 are appropriate preventive and/or corrective treatments for many of the distresses that commonly occur in HMA pavements.

4.0 MATERIALS

Materials play an important role in the efficient and effective use of maintenance treatments. Most materials used in maintenance treatments are covered in the Standard Specifications, SP's or SSP's that can be found on the Caltrans web site http://www.dot.ca.gov/hq/esc/oe/specs_html/index.html. Where the specifications are relevant, they are referenced in the specific treatment chapters 3 through 8. This section discusses the main materials used and provides a general explanation of their composition, manufacturing, storage and handling techniques, and addresses special application requirements. In some cases, the materials themselves are derived from a mixture of raw materials. This section will also address some of these issues.

The two main materials comprising maintenance treatments are binder and aggregate. Binders in use in California include:

- Standard Paving Asphalt – Aged Residue (AR) grade
- Asphalt Emulsion
- Polymer Modified Asphalts, including performance-based asphalts (PBA grades)
- Asphalt Rubber and Modified Binder (MB) grades

Aggregates in use in California cover a range of geological types. The general requirements, gradings and physical properties are covered in various sections of the Standard Specifications (9).

4.1 STANDARD PAVING ASPHALT – AGED RESIDUE (AR) GRADE

4.1.1 *What is Standard Paving Asphalt?*

Conventional paving asphalt is a complex hydrocarbon mixture derived from the refining of crude oil. The crude type and the processing method have a significant effect on the final physical properties (8). In California, steam distilled asphalts are mostly used and are described in the Standard Specifications Section 92.

4.1.2 *How is Standard Paving Asphalt Manufactured?*

Several processes are used to specifically manufacture asphalt including:

1. **Steam Distillation:** Steam distillation begins with the desalting and de-waxing of the crude oil. Once completed, the crude is heated to approximately 300°C (572°F) (8). A furnace is then used to heat the crude to 400°C (752°F) and the heated crude is continuously delivered to the flash zone of the atmospheric tower. The material is separated (by its boiling point) with the most volatile components rising to the top and the less volatile escaping on the sides of the tower. The residue in the tower is stripped using steam to remove volatiles. In some very heavy crudes, this residue may be suitable asphalt.
2. **Straight Run / Blending:** Vacuum tower residue may be suitable as paving asphalt or it may require blending with other feedstocks, fluxes from the vacuum tower, or from other parts of the process such as solvent de-asphalting.
3. **Solvent Refining:** Solvent refining takes advantage of the varying solubility of different asphalt fractions. A short chain hydrocarbon (propane usually) is injected into the asphalt rich fraction and precipitates asphalt fractions out, as they are not soluble in the hydrocarbon. The intent is to remove aromatic oil fractions from the asphalt for other uses (such as extender oils and solvents). Propane precipitated asphalt (PPA) is an asphalt and aromatic rich fraction that may be used as asphalt alone, although it often exhibits tenderness. It can also be blended with other straight run fractions.
4. **Air Blowing:** Air blowing has been used to harden asphalt to create higher viscosity grades. This process may be done continuously or in a batch process. However, this has often led to asphalts with poor aging resistance. Some processes have been developed whereby light blowing is employed to modify feedstocks of specific composition to create multi-grade asphalts of low thermal susceptibility.

The properties of the asphalt produced will depend on its chemical composition, the crude type and the processing method used. The key to producing asphalts that will perform well in the field is the specification.

4.1.3 Specification of Conventional Asphalts

Asphalt is specified by:

- Consistency (or Viscosity)
- Aging Characteristics
- Purity
- Safety

The main conventional asphalts used by Caltrans are aged residue (AR) grades. Table 2 provides the specification for various AR grades, whereas the following paragraphs provide additional details regarding this specification:

Table 2: AR Asphalt Grade Specifications (9)

STEAM-REFINED PAVING ASPHALTS						
SPECIFICATION DESIGNATION	AASHTO TEST METHOD	VISCOSITY GRADE				
		AR 1000	AR 2000	AR 4000	AR 8000	AR 16000
Tests on Residue from RTFO Procedure: (CT 346) ^a						
Absolute Viscosity at 60°C, Pascal second (x10 ⁻¹)	T202	750- 1250	1500- 2500	3000- 5000	6000- 10000	12000- 20000
Kinematic Viscosity at 135°C, min., Square meter per second (x10 ⁻⁶)	T201	140	200	275	400	550
Pen. at 25°C, 100 g / 5 sec., min.	T49	65	40	25	20	20
% of orig. Pen. ^b at 25°C, min.	—	—	40	45	50	52
Ductility at 25°C, mm, min.	T51	1000 ^c	1000 ^c	750	750	750
Tests on Original Asphalt:						
Flash Point, CL.O.C. °C, min.	T48	205	215	225	230	235
Solubility in Trichloroethylene, % min.	T44	99	99	99	99	99
a) TFO (AASHTO Test Method T179) may be used but the RTFO shall be the referee method.						
b) Original penetration as well as penetration after the RTFO loss will be determined by AASHTO Test Method T49.						
c) If the ductility at 25°C is less than 1000 mm, the material will be acceptable if its ductility at 15°C is more than 1000 mm.						

1. **Viscosity:** Viscosity describes the fluidity of asphalt at a given temperature under a given rate of shear. The viscosity will vary depending on the conditions at the time of the test due to asphalt's viscoelastic properties. At temperatures of around 60°C (140°F), unmodified asphalt behavior becomes less shear dependent than at lower temperatures. For this reason, many specifications require that dynamic viscosity be measured at 60°C (140°F). Kinematic viscosity is often used for specifications at higher temperatures 135°C (275°F).

Another consistency test used is penetration. Penetration involves the insertion of a standard needle into an asphalt sample under a standard weight (shear force) over a standard time. The amount that the needle penetrates at 25°C (77°F) loaded with a 100g (3.5 oz) weight over 5 seconds is normally used. Lower or higher temperatures can be used to provide an indication of the temperature susceptibility of an asphalt. California specifications are based on the AR system where consistency is measured on an aged residue. Further detail about aged residues is provided in the next section.

The relationship between penetration grade and viscosity grade asphalt is given in Figure 7. For example, a penetration grade 40-50 has similar viscosity characteristics as an AC-40 or AR 16000. In AR graded asphalts, the aging process increases the viscosity relative to unaged material. Different asphalts age at different rates depending on the crude source and processing method. The initial un-aged properties, in applications not involving hot mix plants (i.e., emulsions) will vary.

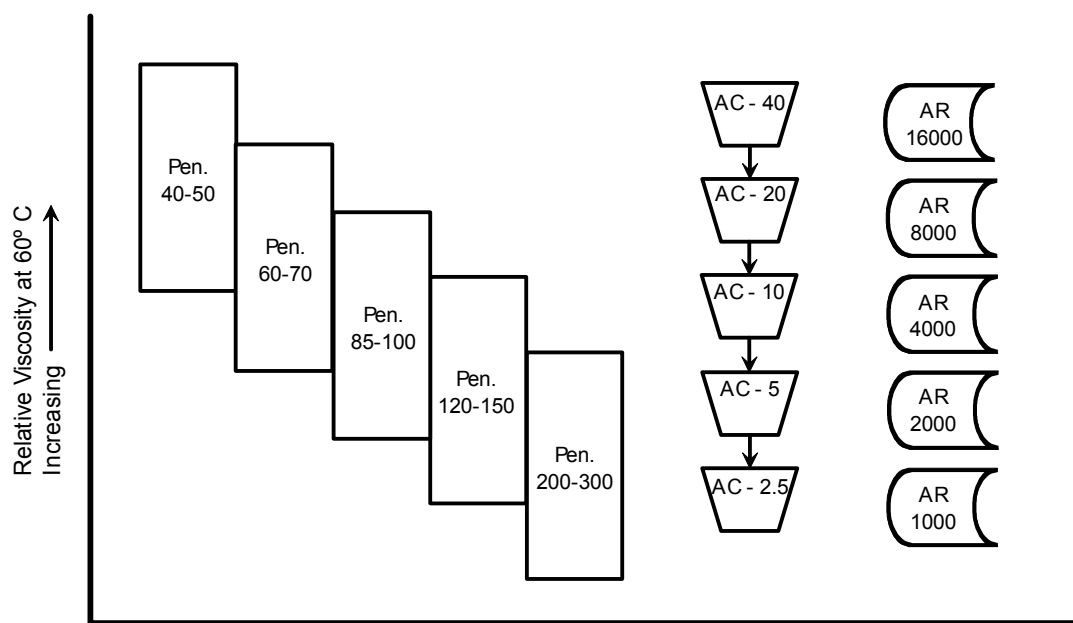


Figure 7: Relationships Between Asphalt Grades by Viscosity (10)

Note: Figure 7 above shows the relationship between grades of asphalt in general viscosity terms and in no way is to be interpreted to determine actual viscosity values.

Other consistency tests include the Ring and Ball Softening Point Test and the Ductility Test. The Ring and Ball Softening Point Test determines the temperature at which the weight of a ball bearing pushes through a circular sample of material. This is a measure of the temperature at which the penetration is approximately 800. Ductility is the elongation of a sample at a set temperature and set strain rate. Ductility indicates the colloidal stability or internal cohesion of the asphalt.

2. **Aging Characteristics:** Aging in asphalt is associated with oxidation and hardening of the asphalt. During processing and while in service in the pavement, asphalt will lose volatile materials. The loss of this volatile material can lead to hardening. Aging is one cause of asphalt failure as the material becomes brittle, shrinks, and cracks. Specification of short-term aging characteristics is usually determined after exposure to air in a thin film oven or rolling thin film oven. Aging during service life is measured using a pressure aging vessel test (AASHTO T-49). This is currently not used in California.

In the AR specification, the properties of the asphalt are measured after these aging tests are performed. In California a rolling thin film oven test is used (California Test Method CT 374).

3. **Purity and Safety:** Purity tests are based on the solubility of the asphalt in solvent, with Trichloroethane the most commonly used. Safety tests are based on the flammability or flash point of the fumes emitted by asphalt during heating. Caltrans uses the Cleveland Open Cup test to determine the flash point for asphalt binder material.

AR asphalts are used in all conventional mixes. The higher the designation number the higher the in-service viscosity. For example, AR 4000 has a higher in-service viscosity than AR 2000. The higher the in-service viscosity, the harder or stiffer the asphalt. Stiffer asphalt produces higher stability in mixes and resistance to deformation. Conversely, stiffer asphalt may result in lower resistance to cracking.

4.2 ASPHALT EMULSIONS

4.2.1 *What is an Emulsion?*

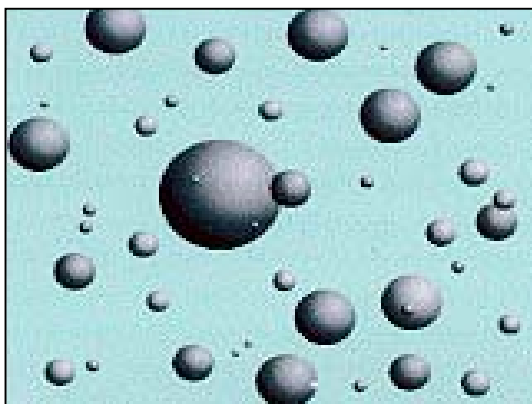
When two or more solid components are mixed together in water, several phenomena can occur depending on the chemistry of the components. If the solid materials are broken down or reacted with water, then a solution may form. In a solution, the solid phase is in an ionic form and is dispersed on a molecular level (e.g., salt in water). If the solid materials do not change or react with the water they may form a slurry or suspension (13, 14, 15).

An emulsion lies between these two extremes and is defined by the size of the particles involved. In an emulsion, the particle sizes range from 1 to 100 μm (3.94×10^{-5} to 3.94×10^{-3}) in diameter. This allows the particles (once chemically stabilized) to form a stable dispersion. When the particle size is less than one micron, the material is termed a colloid. Such systems may be stable without the use of extra chemical stabilizers as they are usually self-stabilizing (e.g., clay in water).

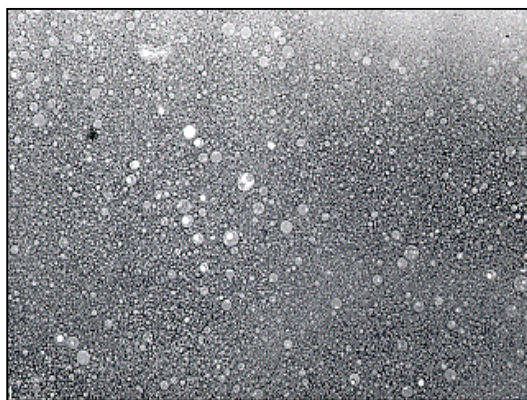
An emulsion is a dispersion of one immiscible phase in another. An asphalt emulsion is asphalt dispersed in water. This is not a solution as the two phases (oil in water) are susceptible to separation. So, like a good salad dressing, the oil is stabilized with an emulsifier to keep it dispersed. Figure 8 shows an emulsion in schematic and an emulsion micrograph.

The process of returning from this dispersed form to the asphalt form is called “breaking” (13). The process by which the asphalt expels water and dries to an integral film or layer on the aggregate or surface is termed “curing” (13). The mechanisms associated with breaking and curing are covered in Section 4.2.4.

Emulsions allow the formation of an asphalt binder with low enough viscosity for easy application. The dispersion in water gives the asphalt many of the properties of water such as low viscosity, lower temperature requirements for both application and storage, and less sensitivity to application on damp surfaces.



a) Emulsion Schematic



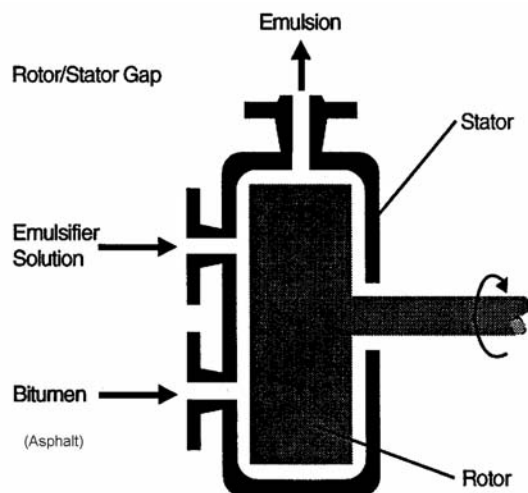
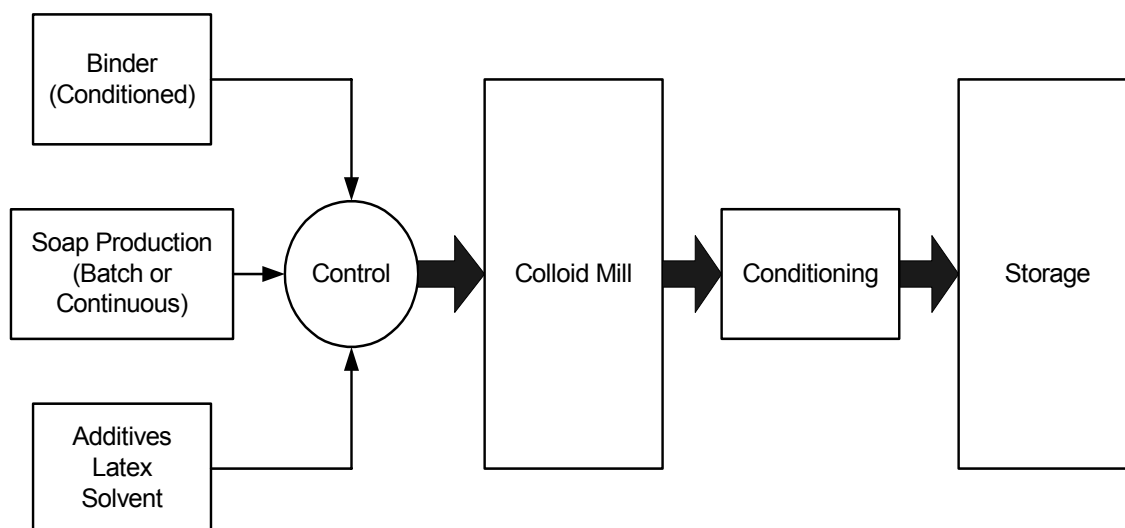
b) Emulsion Micrograph

Figure 8: Asphalt Emulsion Illustrations (13)

4.2.2 How are Emulsions Made?

Asphalt is semi-solid at ordinary temperatures 10 to 60°C (50 to 140°F). To make an emulsion, the asphalt must be sheared into small droplets and coated/ reacted with a chemical stabilizer or emulsifier. Figure 9 shows the cross section of a typical colloid mill, the device that is used to shear the asphalt. It should be noted that there are other methods of shearing the asphalt to produce an emulsion. These include homogenizers, pressure reducers (venturi effect) and pumps. The colloid mill is the most commonly used to produce asphalt emulsions. The chemical emulsifier solution (also known as the soap solution) is combined with the asphalt and introduced into a gap between a high-speed rotor and a stator (or other rotor rotating at a lower speed). The resulting shear breaks the asphalt particles down to the required size. The geometry of the sheared particles has a big effect on the particle size distribution, which in turn affects the properties of the emulsion (16).

In an emulsion plant several operations must be carried out. Figure 10 shows the key elements of an emulsion plant.

**Figure 9: Colloid Mill Cross Section (13)****Figure 10: Emulsion Plant Operations Schematic (14)**

The asphalt must be stored correctly and at the right temperature. For normal operation (non polymer binder emulsification), the storage temperature will range from 135 to 140°C (275 to 284°F). For polymer-modified binders, the storage temperature will range from 160 to 170°C (320 to 338°F). If higher temperatures are required, the colloid mill must be operated under back pressure, about 2 to 3 bar (29 to 43 psi) and a heat exchanger on the mill outlet is required to ensure that the emulsion is cooled to below boiling temperatures before the back pressure is reduced to atmospheric pressure. If the backpressure and heat exchange operations are not properly carried out, the emulsion will boil and be destroyed.

The soap solution (emulsifier solution) preparation is required because the emulsifiers usually need to be reacted with a base or acid to create the surface-active or emulsifying form (salt). This may be done in a continuous fashion or in a batch fashion. As the reactions are between an acid and an alkaline emulsifier (cationic systems) or an alkaline chemical and an acid emulsifier (anionic systems), the pH of the soap solution and the pH of the resulting emulsion are key factors in the quality of the emulsion.

In many cases, additives for emulsion stability or modification are introduced. The most common method of modifying an emulsion is through the addition of rubber latex (synthetic or natural). The latex is either introduced via the soap solution or directly injected into the mill via the soap line. This method has the advantage that no heat exchanger or pressure operation is required.

4.2.3 What are Emulsifiers and What Types of Emulsions are Used?

Emulsifiers in their neutralized state may have a negative charge (anionic), a positive charge (cationic), or no charge (nonionic) (13). The exact chemistry and type of emulsifier determines the application of the finished emulsion. Other factors that determine physical and application characteristics include pH of the emulsion, the binder content, the particle size and distribution, and the compatibility with the aggregate sources.

Anionic emulsifiers are based on fatty acids. These are reacted with a base such as caustic soda to produce an acid salt. This acid salt is the active emulsifier (see Figure 11). The emulsifier has a long fatty chain that is soluble in the asphalt and a polar head that provides a surface charge (see Figure 12). Repulsion created by these charges allows stabilization of the emulsion.

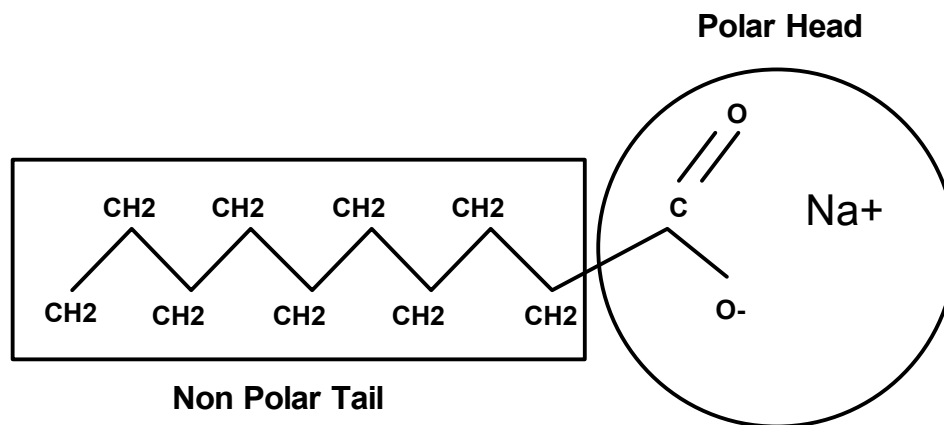


Figure 11: Chemical Structure of an Anionic Emulsifier (15)

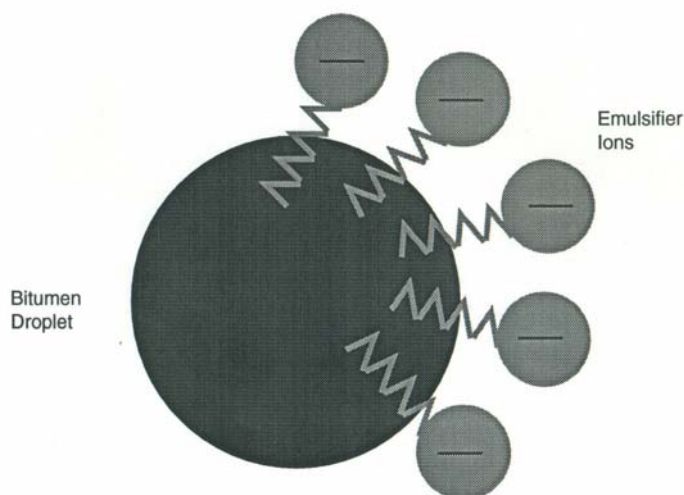


Figure 12: Anionic Emulsified Asphalt Particle (15)

Cationic emulsifiers are based on amines of various types. The exact type used will depend on the application. Some typical types include quaternary ammonium compounds (slow set), fatty diamines (rapid set), amidoamines (quick set) and imidazolines (microsurfacing). These are reacted with an acid such as hydrochloric acid to produce a salt, which is an active emulsifier. The emulsifier has a long fatty chain that is soluble in the asphalt and a polar head that provides a surface charge. Repulsion created by these charges allows stabilization of the emulsion as may be seen in Figures 13 and 14.

Nonionic emulsifiers are amphoteric; that is, at low pH they have a positive charge and can be cationic, at high pH levels they can have a negative charge and can be anionic emulsifiers.

The emulsifier type and concentration determines the emulsion's performance. The emulsifier type may control the break period. More rapid break times equal higher charge and lower concentrations of emulsifier. Slow break times equal lower charge, and higher concentrations of emulsifier.

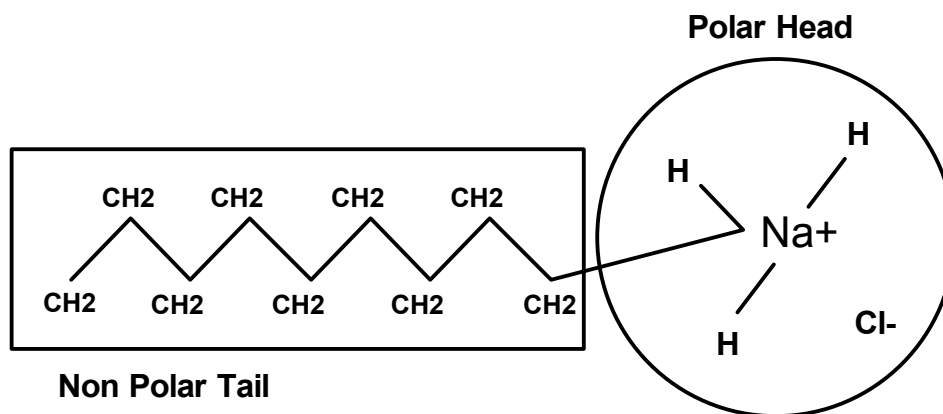


Figure 13: Chemical Structure of an Cationic Emulsifier Particle (15)

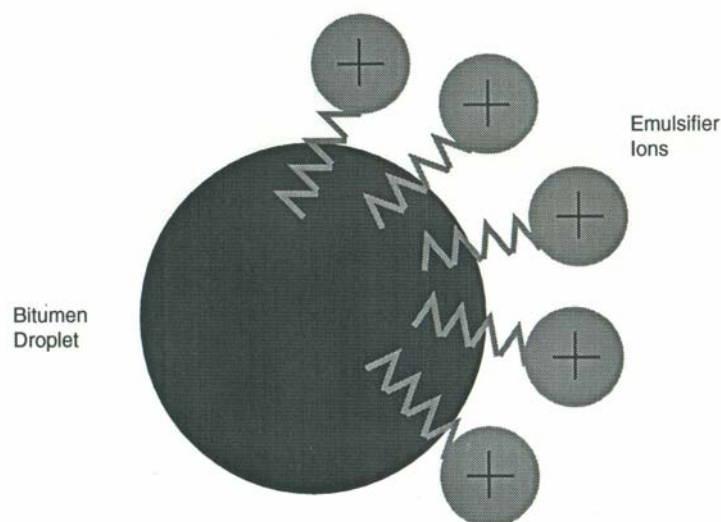


Figure 14: Cationic Emulsified Particle (15)

4.2.4 Anionic or Cationic: Which to Use?

Caltrans uses emulsions for various applications; however only anionic and cationic emulsions are utilized. The choice between anionic and cationic is made based on the application requirements and the characteristics of the aggregate to be used in the mix. Generally, anionic emulsions of the slow set variety are more compatible with soils and easier to dilute with water. Thus, they are normally chosen for soil stabilization and fog seals. Anionic emulsions break by flocculation and coalescence. In this process, as water evaporates from the emulsion and the particles come into close contact, they stick together, as illustrated in Figure 15. These particles then “floc” or coalesce into larger particles. This process continues until the particles begin to form films. No specific reaction occurs with siliceous aggregates, but with calcareous aggregates a reaction does occur (17). Thus, anionic emulsions are suitable for use with calcareous aggregates such as limestone.

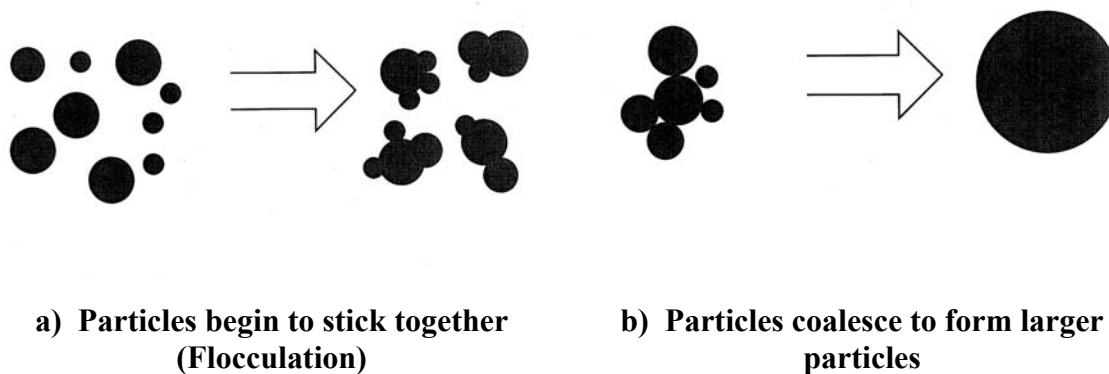


Figure 15: Particle Coalescence Process (15)

Figure 16 illustrates material compatibility in general terms along with the associated breaking process. Cationic emulsions may be formulated for all application types and aggregates, which is also illustrated in Figure 17. These emulsions are most useful for rapid setting chip seals, slurry emulsions and microsurfacing emulsions. This is due to a cationic emulsion's specific reaction with all compatible aggregates that creates a stronger adhesive bond. For the same reason, cationic emulsions are also less susceptible to cooler conditions and dampness than anionic emulsions.

Material	Cationic emulsion	Anionic emulsion
Electropositive materials (calcium, basalt)	Neutralizing reaction <div style="text-align: center;"> <div style="border: 1px solid black; padding: 2px; width: 100px; margin: 0 auto;">BREAKING</div> <div style="text-align: center;">forming of insoluble amine carbonate</div> <div style="border: 1px solid black; padding: 2px; width: 100px; margin: 0 auto;">ADHESIVENESS</div> </div>	attraction <div style="text-align: center;"> <div style="border: 1px solid black; padding: 2px; width: 100px; margin: 0 auto;">BREAKING</div> <div style="text-align: center;">forming of insoluble calcium soap</div> <div style="border: 1px solid black; padding: 2px; width: 100px; margin: 0 auto;">ADHESIVENESS</div> </div>
Electronegative materials (silex, quartz, granite)	attraction <div style="text-align: center;"> <div style="border: 1px solid black; padding: 2px; width: 100px; margin: 0 auto;">BREAKING</div> <div style="text-align: center;">forming of insoluble amine silicate</div> <div style="border: 1px solid black; padding: 2px; width: 100px; margin: 0 auto;">ADHESIVENESS</div> </div>	no neutralizing reaction no attraction

Figure 16: Material Compatibility and Reactivity of Emulsions (17)

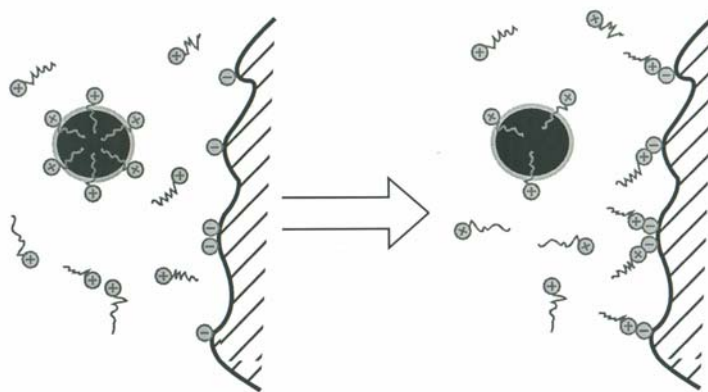


Figure 17: Cationic Emulsion Physio-Chemical Reaction with Aggregate (15)

The curing process (illustrated in Figure 18) is the same for both types of emulsion, except the reaction mechanism for cationic emulsion pushes water away from the aggregate surface. Thus, cationic emulsions tend to cure faster.

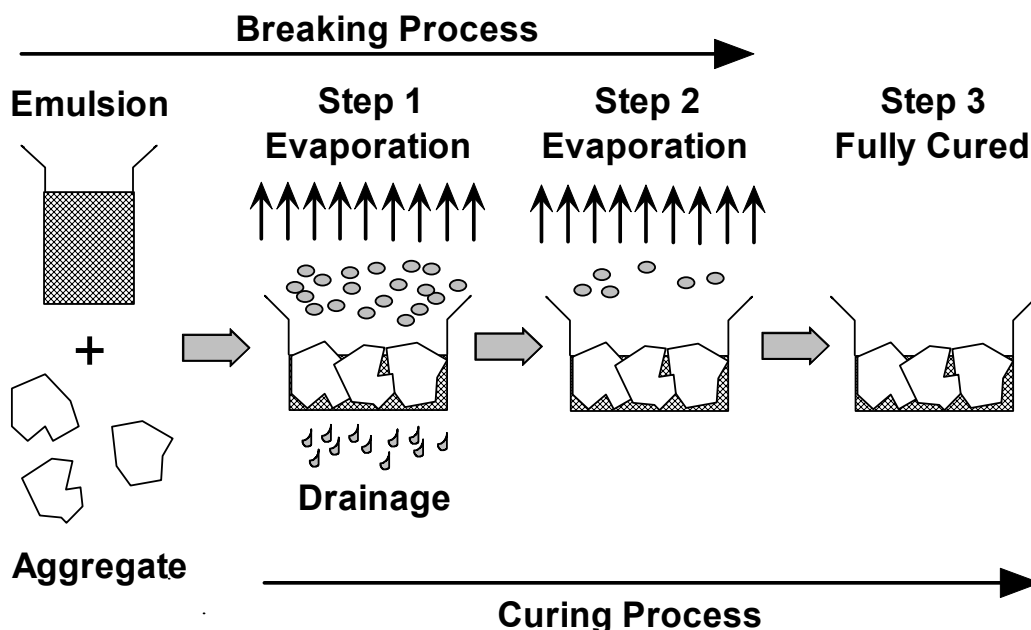


Figure 18: Emulsion Break and Cure Stages (15)

The decreased curing time for cationic emulsions has implications in the application and handling of these emulsions. These implications will be discussed in the sections on specifications and storage and handling.

4.2.5 Specifications and Testing

1. **Caltrans Specifications:** Caltrans uses several common emulsion types. These are described in detail in Standard Specifications Section 94 (9), and are briefly described below:
 - **Anionic Emulsions:** Rapid Set (RS), Medium Set (MS) and Slow Set (SS). There are subcategories that describe the base asphalt ("h" equals hard or 80/100-penetration grade or if there is no 'h' designation, it refers to the use of a softer grade- 120-150 pen grade). Numbers describe the binder content of the emulsion (1 for lower and 2 for the higher level). In anionic emulsions, these binder content designations are different for different grades; RS-1 is typically 55% minimum binder content, and RS-2 contains 65% minimum. Medium sets are 55 and 65% respectively and SS grades are only designated as SS-1 or SS-1h and are 57% minimum binder content.
 - **Cationic Emulsions:** Rapid set (CRS), Medium set (CMS) and Slow set (CSS). There are subcategories that describe the base asphalt ("h" equals hard or 80/100-penetration grade. If there is no 'h' designation, it refers to the use of a softer grade). Numbers describe the binder content of the emulsion (1 for lower and 2 for the higher level). In cationic emulsions, these binder content designations are different for different grades; CRS-1 is 60% minimum binder content, and CRS-2 65% minimum. Medium sets are 55 and 65% respectively and SS grades are only designated as CSS-1 or CSS-1h and are 57% minimum binder content.

- **Polymer Modified Emulsions:** These may be anionic or cationic. They are all rapid set and have the letter P at the start of the designation. For example PMCRS-2h is a polymer modified cationic rapid set emulsion with the hard binder. All the emulsion binder contents for this class of emulsions are 65% minimum. These emulsion types are further discussed in Chapter 4 “Chip Seals”.
 - **Quickset Slurry Emulsions:** These may be anionic or cationic (QS or CQS) and have minimum binder contents of 57%. In general use are polymer modified (latex) versions of these emulsions and they have the letter “L” preceding the designation (e.g., LMCQS-1h). Such emulsions may be made with the hard binder or the softer binder. This is further discussed in Chapter 7 on Slurry Surfacing.
2. **What the Specifications Mean:** The test methods listed in the specifications (9) are designed to provide an indication of the stability, physical characteristics, and performance of the emulsion. This section presents a general overview of tests contained in the specifications.
- Binder content is measured by distillation or evaporation. This is important to know because application rates are based on residual binder.
 - Viscosity indicates the application properties (whether the emulsion can be pumped and sprayed) and whether it will remain where it is applied without running off. The viscosity of an emulsion is a function of the binder content within the emulsion, as illustrated in Figure 19. This figure indicates that as the binder content of the emulsion increases, so does its viscosity. Emulsions with higher viscosities are more difficult to pump and spray at a given temperature than are emulsions with lower viscosities.
 - Settlement and storage stability are determined by the same test, but performed over different periods of time. They determine if an emulsion can be stored without “breaking” in the storage container. If settlement occurs during the test (as shown in Figure 20), and is not re-dispersed, this is an indication that the emulsion may flocculate and coalesce (“break”) during storage.
 - Demulsability is the measure of an emulsion’s resistance to breaking and gives an idea of whether the emulsion is rapid or slow setting.
 - The coating test refers to mixing characteristics with soil or aggregate.
 - The cement-mixing test is a stability test that is relevant for mixing emulsions with soils or aggregates.
 - The sieve test provides an indication of foreign matter in the emulsion that might cause problems such as clogging nozzles during spraying or clogging in-line sieves during pumping operations. It is also an indication of stability. Figure 21 illustrates the Sieve Test.

Tests on residual binder are carried out to check the base asphalt and the polymer. Penetration and ductility are conducted on the residue of both conventional and polymer modified emulsions. Torsional recovery and infrared testing are used to examine polymer content. Torsional recovery is carried out using the equipment shown in Figure 22. The recovery from a torsional load is measured and related to polymer content (the test method used is CT 332).

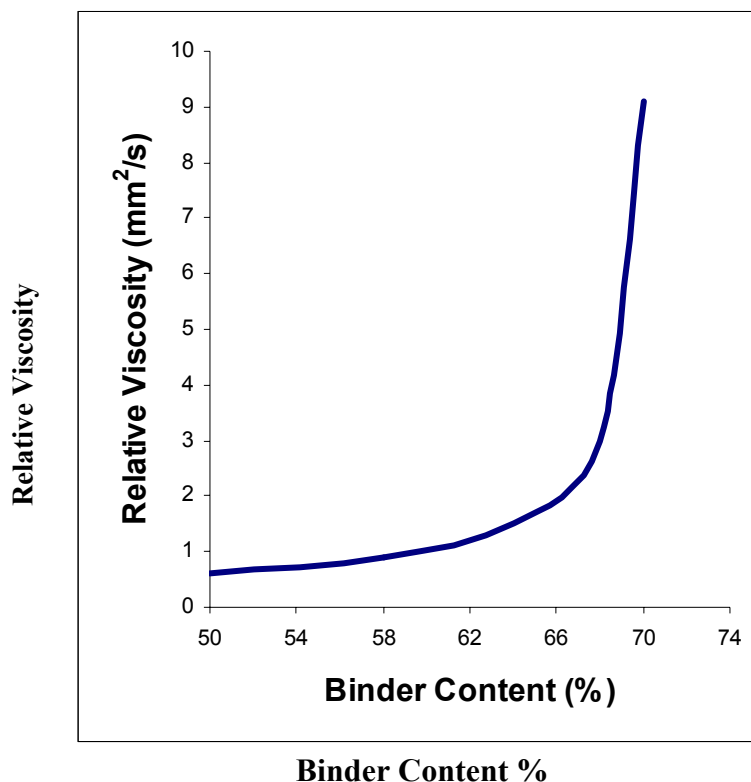


Figure 19: Relative Viscosity Vs Binder Content (18)

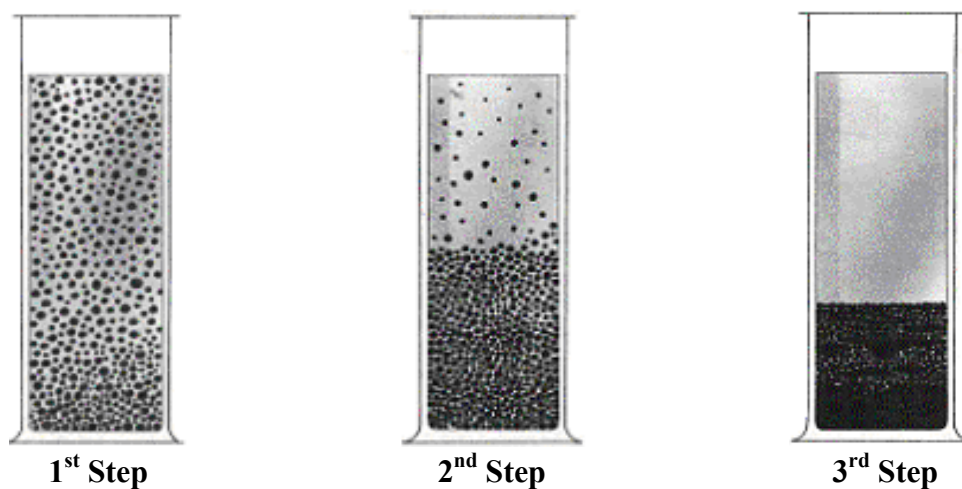
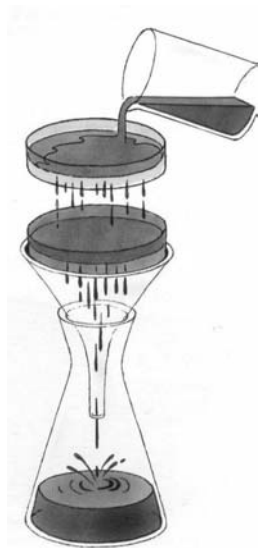


Figure 20: Settlement and Storage Stability Test (17)

**Figure 21: Sieve Test**

(Note: Normally only 1 sieve is used in the AASHTO T-59 as used by CT) (17)

**Figure 22: Torsional Recovery Test**

4.3 CUTBACKS

4.3.1 What are Cutbacks?

A cutback is a solution of asphalt in a hydrocarbon solvent (e.g., kerosene, diesel, or naphtha). Solvents are used to reduce the asphalt's viscosity so that the cutback can be pumped and sprayed at lower temperatures [40 to 145°C (104 to 293°F)] than that required for conventional asphalt. The solvent performs no other function in road applications. The solvent selected depends on the grade of the cutback, which in turn, is based on the expected setting rate.

During the 1970's energy crisis and in response to environmental concerns on volatile emissions (i.e., evaporation of the solvent during the application and curing processes), use of cutbacks has generally been discontinued. In California, only slow and medium cure cutbacks are still made and only slow cure cutbacks are generally specified. The main use for cutbacks is prime coats over aggregate base materials prior to placement of an asphalt-wearing course in new construction.

4.3.2 Manufacturing

Because cutbacks are solutions of asphalt and solvent, they are easily manufactured. This can be done on site by circulation in a tank. In refinery applications, inline blending or emulsion colloid mills have been used to manufacture cutbacks.

4.3.3 Specifications and Testing

The Caltrans cutback specifications are found in the Standard Specifications Section 93, and they are referred to as “Liquid Asphalts” (9).

- Slow curing (SC): these contain a heavy oil solvent. Caltrans has four designations SC-70, SC-250, SC-800, and SC-3000. The number refers to kinematic viscosity of the cutback.
- Medium Cure (MC): these are made with a kerosene type solvent and have the same viscosity designations as SC grades.

The main specifications relate to safety as measured by flash point and water content, viscosity and boiling range of the solvent, application and cure rate, residue percentage for residual application rate, and residue tests to ensure the correct base asphalt grade had been used. The main effect of increasing the viscosity is to increase the application temperature requirements. This is covered in the Standard Specifications Section 93.

4.4 POLYMER MODIFIED BINDERS (PMB'S) & PERFORMANCE BASED ASPHALTS (PBA'S)

4.4.1 What are Polymers and Polymer Modified Binders?

Polymers are large molecules that enhance the properties of virgin asphalt. Depending on the basic polymer units or monomers used, a wide range of properties can be achieved. It is possible to categorize polymers in a number of ways, but for engineering purposes they are conveniently described as having glassy (stiffness) or rubbery (elastomeric) properties. Often this is termed plastomeric or elastomeric. However, this is very dependant on conditions such as temperature, rate of loading and strain level (19). As the demands of a modern road system have, in some areas, exceeded the capacity of conventional bituminous materials, polymer additives are a means by which pavement performance may be enhanced.

The use of a polymer has no value if it does not substantially improve the life cycle cost of the material in which it is used or solve a specific problem. The selection of polymer modification should almost always be based on improved performance related to cost. Although there are a substantial number of polymers in use today for a variety of products, only a relative few are commonly used in asphalt mixtures (21). Examples of polymers commonly used in asphalt mixtures include:

- Styrene Butadiene Copolymer (radial and linear) (SBS)
- Polyethylene (PE)
- Styrene Butadiene Rubber (SBR)
- Polybutadiene (PB)
- Ethylene Vinyl Acetate (EVA)
- Ethylene Methyl Acrylate (EMA)
- Atactic Polypropylene (PP)
- Epoxies and Urethanes
- Tire Rubber (Crumb)

4.4.2 How Polymer Modified Binders are Manufactured

Many types of manufacturing configurations exist to make polymer-modified asphalts. Manufacturing may be done at high or low shear, on site, or in a factory. The main stages of manufacturing require the following procedures:

- Metering of polymer, asphalt, and additives.
- Wetting of the polymer by the asphalt/additive mix.
- Dispersion of the polymer.
- Allowance for any interaction (reaction) of the polymer with the asphalt.
- Storage and transportation.

Most of these are mechanical issues and are achieved by relatively simple techniques. Figure 23 illustrates a typical manufacturing (blending) plant.

The most important steps in the manufacturing process are dispersion and reaction. This is what determines the structure (i.e., morphology) of the final binder and hence its properties. These steps also determine the level of polymer required to achieve the desired results. Compatible systems usually have superior rheological, aging, and stability properties to those of incompatible systems at the same polymer level (19). The micrographs in Figure 24 show the structure (morphology) of SBS at 3% dispersion in a compatible (a) and incompatible (b) polymer system. The scale for both micrographs is the same.

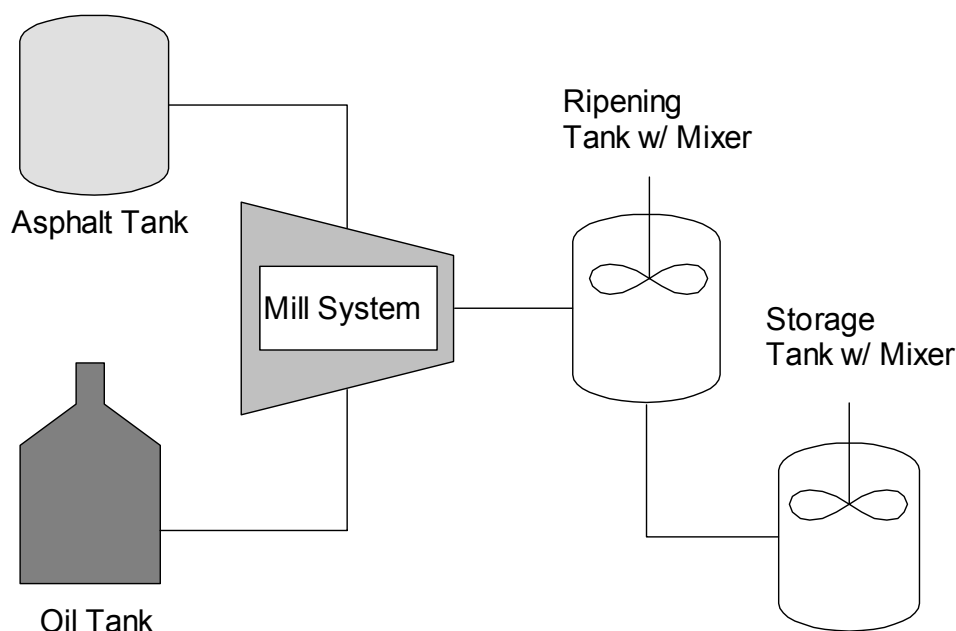


Figure 23: Typical Polymer Blending Plant (19)

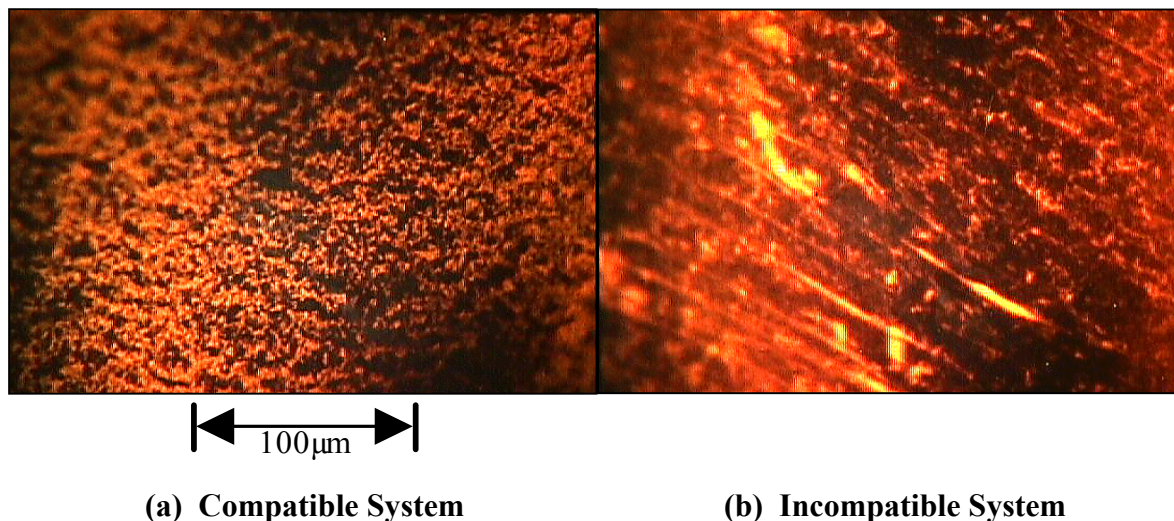


Figure 24: Micrographs of Polymer Systems (19)

4.4.3 What are Performance Based Asphalts?

Caltrans was one of the originators of performance-based asphalts (PBA's) as detailed in SSP S8 M-20 (23). Some PBA's are polymer modified, notably PBA 6a, PBA 6b, and PBA 7. The PBA specification defines the performance characteristics of the binder. It also incorporates many of the standard consistency tests as well as some items that were a precursor to the Strategic Highway Research Program (SHRP) rheological parameters, such as shear susceptibility of delta and viscosity.

The different grades are suited for different climatic applications. PBA 1, the base conventional material, is similar to AR 4000. PBA 6a and PBA 6b are polymer modified asphalts and provide better high and low temperature properties than AR grades and are used in areas with hot summers and cold winters. This is achieved through the use of SBS copolymers. The main difference is the lower temperature cracking resistance, PBA 6b being superior to PBA 6a by 5 to 6°C. Both products resist rutting at very high pavement temperatures. PBA 6a is also useful in open graded mixes where the application temperatures are at the lower end of the requirements or work is being done at night. This is possible due to PBA 6a's good compaction characteristics in such mixes. PBA 7 is more heavily modified than the other materials and is suitable for high desert areas. This material has better aging resistance and may be used for this purpose in milder climates.

4.5 ASPHALT RUBBER?

4.5.1 What is Asphalt Rubber?

Scrap rubber, crumb rubber, and reclaimed rubber are all terms describing recycled rubber. The largest recycled rubber source is automobile and truck tires and is referred to as crumb rubber modified (CRM). This rubber is not a pure polymer but a blend. Most car tires in the USA are made of mainly Styrene Butadiene Rubber (SBR) or polyisoprene and carbon black. Other polymers are included in some blends, and tires are not uniformly formulated or compounded. Truck tires generally contain a higher percentage of natural rubber than car tires (up to 30% of the combined polymer content).

The variations in the CRM may affect the properties. However, in asphalt rubber binders, the particle size of the added CRM is relatively large and the chemical properties are less important than in a polymer system. Asphalt rubber binder is typically made in the field; that is, near to the job site for chip seal applications or at the hot plant site for hot mix applications.

The asphalt rubber specification is a recipe specification and is detailed in the SSP's (23). Two rubber types are specified, one is tire rubber and the other is a high natural rubber recycled material. The required rubber properties are controlled by the SSP requirements (23). Mixing temperatures are important and should be kept between 190 and 226°C (375 and 440°F). Grading is important in determining the rate of digestion and the binder's final properties. These materials are mixed into asphalt that has been modified with extender oil (high aromatic hydrocarbon) at about 2% (23).

The asphalt rubber binder improves fatigue life, resistance to rutting, and provides stone retention and crack alleviation in chip seals (25) when compared to other binders. In California, asphalt rubber gap-graded overlays may be reduced up to 50% the thickness of conventional overlays and still provide the same resistance to reflective cracking. Caltrans uses asphalt rubber binders mainly in gap graded and open graded mixes. They are also used as SAM and SAMI seals as a reflection cracking treatment. Caltrans does not currently use asphalt rubber in dense graded mixtures.

4.5.2 How is Asphalt Rubber Manufactured?

To produce asphalt rubber binder, the neat asphalt is heated to approximately 190 to 226°C (375 to 440°F) at which time the tire rubber is added via a hopper system into a pre-wet tank. The asphalt contacts and wets the CRM particles. This mix is then transferred into a reaction vessel where it "reacts" with the lighter fractions in the asphalt, mostly aromatic and naphthenic oils that swell the outer areas of the particles.

A reaction is claimed to occur in which the asphalt and the rubber particle interact to form a gel coated particle (25). This reaction is similar to the process of swelling that occurs in polymer asphalt systems (22). The reaction is shown schematically in Figure 25.

How well this model reflects the actual situation and the relative effect of particle sizing is not clear but, based on polymer and asphalt chemistry, it seems adequate. It also explains why a significant change in properties occurs over time, since this type of system is not thermodynamically stable. Further, the large increase in viscosity over its early life is due to the continuation of this solvation process (28, 29).

This can be shown by examining micrographs (see Figure 26) of asphalt rubber digested with and without extender oil (relative sizing is important; all micrographs are to the same scale and the largest particles are 100µm).

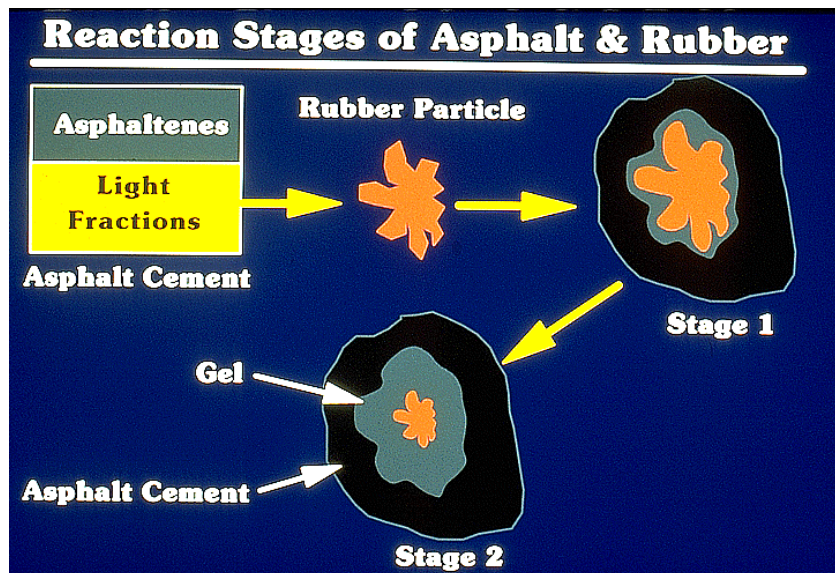
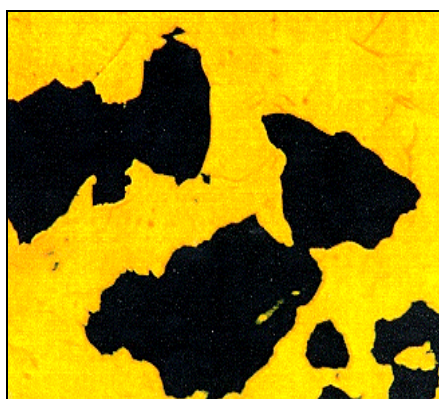


Figure 25: Asphalt Rubber “Reaction” (25)



100µm

a) Without Extender Oil



b) With Extender Oil

Figure 26: Micrographs: Asphalt Rubber Extender Oil Effects (19)

4.6 AGGREGATES

4.6.1 What are Aggregates?

Aggregates are the major building material for pavements. The aggregate's role is to form the matrix of strength in a mix; as such their properties are critical to the success of a mix (10). Local sources are generally used but some other materials such as expanded clay (light weight aggregate) or slag may be used if they meet the required specification. Major aggregate types that may be encountered in California include (10):

- **Igneous rocks:** Volcanic rocks formed from molten rock. Examples are granite and basalt.
- **Sedimentary rocks:** Rocks formed by the laying down of layers of material that is then compressed. Examples include limestone, sandstone, and chert.
- **Gravel:** Formed from the breakdown of any natural rock. Usually found in rivers or waterways. River gravel is an example.
- **Sands:** These are formed from the deterioration of any natural rock. These often contain clay or silt and should be washed.
- **Slag:** This is a by-product of metallurgical processing. Slags can be from tin, steel, or copper processing. Slag is generally hard but absorbent.

There are two major categories of aggregate properties of interest in pavement applications. These are the chemical and physical properties as discussed below:

Chemical Properties: Chemical properties of aggregates identify the changes an aggregate may go through due to chemical action. Some aggregates contain substances that are soluble in water, are subject to oxidation, hydration or carbonation. The main chemical property that affects asphalt applications, however, is affinity the aggregate has for the asphalt. Asphalt must wet the surface of the aggregate and adhere to it. Failure to do so may produce the phenomena of stripping and disintegration failure of the hot mix or loss of stone in other treatment types such as slurry or chip seal. No reliable indicators exist for determination of stripping potential based on chemistry of the aggregate alone and most tests are based on testing the mixture (AASHTO T283).

Physical Properties: The most important aggregate properties are listed below:

- **Grading or Particle Size Distribution:** Grading requirements are discussed in the chapters that deal with individual treatments. Caltrans specifies grading requirements for use in HMA in the Standard Specifications Section 39. The grading is important as it determines the mixture characteristics with respect to its physical properties. For example, in HMA this includes fatigue resistance and load bearing. In open graded asphalt concrete mixtures, it will determine porosity, while in chip seals and slurry surfacing it will determine seal durability. The individual grading requirements are further discussed in the chapters on treatments 3-8. CT 202 and CT 105 measure grading. The latter test method is used if there is a difference in specific gravity of 0.2 or more between the coarse and fine portions of the aggregate or between blends of different aggregates.
- **Cleanliness or Presence of Deleterious Materials:** Dirty aggregates may cause adhesion problems in chip seal and HMA and cohesion problems in slurry surfacing. Lumps of clay may disintegrate under freeze thaw conditions or cause pockmarks in a HMA pavement. Specific testing and requirements are discussed in the chapters concerned with treatments. The Sand Equivalent test (CT 217) is used to measure this property for HMA aggregates.
- **Hardness or Abrasion Resistance:** Aggregates transmit the wheel loads to the subgrade. They must be resistant to crushing and wear to maintain this function. They must also resist crushing and degradation during stockpiling. A polished or worn aggregate will reduce skid resistance. The LA abrasion test (CT 211) is used to measure hardness and abrasion resistance.

- **Durability or Soundness:** Aggregates must be resistant to break down due to the cyclic action of wetting and drying and freeze and thaw cycles. CT 214 can be used to determine soundness.
- **Particle Shape and Surface Texture:** Aggregate particles for use in most treatments should be cubical rather than flat or elongated. This creates more interlock and internal friction in generating higher deformation resistance. In chip seals, it creates greater seal texture depth and skid resistance. The surface texture and the shape are a determinant to workability in mixes and may affect compaction. A rough fractured particle has a higher surface area and forms tougher adhesive bonds. Caltrans measures only fractured faces (CT 205).
- **Absorption Characteristics:** Aggregates may absorb asphalt; reducing the effective volumetric percentage of the binder mixtures or the effective application rate in chip seals. These changes can result in raveling of the pavement. Caltrans uses the Centrifuge Kerosene Equivalent and the Oil Ratio Test (CT 303) test to measure the absorption of aggregate.

Special aggregate requirements for specific treatments are considered in the relevant chapters.

4.6.2 *How are Aggregates Manufactured?*

Aggregates are manufactured in quarry operations by first blasting (if necessary) and then using a series of crushers and screens to create the desired stone sizes. Several methods of crushing may be used; which include jaw crushers (usually the primary crusher), impact crushers (these produce cubical aggregates and are generally used later in the process), attrition mills, hammer mills and gyratory cone crushers. The combination must be chosen to meet the required specifications.

5.0 STORAGE AND HANDLING

The key aspects of storing and handling any product include safety and quality. It is essential to ensure safety in handling at all times and to maintain quality so that the material remains in specification from manufacture to the intended end use.

This section covers storage and handling of:

- Conventional Asphalt
- Modified Asphalts (including asphalt rubber and MB's)
- Asphalt Emulsions
- Aggregates

5.1 CONVENTIONAL AND MODIFIED ASPHALTS

When handled properly, asphalts may be reheated or maintained at elevated temperatures without adverse effects. If asphalt is thermally abused in storage, handling or application, it may harden and compromise service properties.

5.1.1 Avoiding Problems During Storage

The main methods of avoiding potential storage problems are to ensure that equipment is properly designed, in good working condition and correct procedures are established and followed. All tanks should be designed in accordance with a recognized standard (e.g., API 650). General design considerations include tank shape, tank foundations, tank thickness, and tank access. Best management practices require a secondary containment around all tanks. Vertical tanks yield the highest asphalt to tank volume ratio of all tank configurations. Vertical tanks with a cone shaped roof are preferred, although temporary storage in horizontal tanks is acceptable. The operational tank design considerations relate to:

- **Minimizing the risk of overheating:** The tank requires accurate thermal sensors. They should be positioned in the region of the heaters and also uniformly distributed throughout the tank. The probes should be in thermal wells and removable for cleaning and calibration. Heating may be accomplished via heat transfer (oil or steam), electric coils, or direct fired. As asphalt is a good insulator, the heating rate must be controlled to prevent localized overheating, particularly when direct-fired systems are used. The heat capacity may be estimated as 0.5 and heating rate should be limited to 25°C (77°F) per hour (30).
- **Minimizing oxidation and loss of volatiles:** In order to minimize oxidation and loss of volatiles, contact with air must be minimized. This may be accomplished by designing pressure-tested, fully enclosed tanks. To avoid air entrainment, all circulation lines should re-enter the tank under the liquid level. When filling a tank, it should be filled from the bottom and the asphalt should not be allowed to freefall as this can result in entrapped air. Venting is an essential safety precaution and cannot be eliminated to reduce oxidation.
- **Maintaining asphalt homogeneity:** To maintain asphalt homogeneity and avoid temperature variation, the asphalt should be mixed on an intermittent basis. This may be done through circulation or through the use of side mixers under the liquid level. Vortex mixing entrains air and its use should be avoided. When adding fresh asphalt to a tank, circulation is necessary to stabilize temperature and combine the existing material with the fresh material.
- **Minimizing heat loss:** To conserve energy, all tanks should be insulated with fiberglass or rock wool insulation. This insulation should be at least 50 mm (2 in) thick and sheathed in aluminum or galvanized steel at least 0.7mm (0.03 in) thick. Additionally, lines should be insulated and heat traced with electric tape, steam or oil.

Safety hazards can arise from:

- **High Temperatures:** Since asphalt must be stored at high temperatures, safety issues involving burns, along with the material's contact with water, which causes rapid expansion resulting in foaming and explosive boil over, must be addressed. Burns may be avoided by always using the correct safety apparel. Additionally, ensure that all lines and surfaces are thoroughly insulated.

Due to the potentially hazardous side effects of water contacting high temperature asphalt, steps need to be taken to avoid this interaction. As water is slightly lighter than asphalt, it will move to the top of tanks. However, during transport cold water may migrate to the bottom of a tank. Water entrapment in tanks can be avoided by using watertight cone topped tanks, ensuring that tanks are watertight and hatches are sealed. Water finding gel should be used to check tanks before filling. If water is present, the asphalt should be heated through the range from 92 to 125°C (198 to 257°F) at a rate of 10 to 15°C (50 to 60°F) per hour. Silicone antifoaming agent at 0.1 % can also be added. Pipes and any additives that are to be blended with the asphalt need to be checked for water.

- **Flammable or explosive atmospheres:** Asphalts normally have flash points exceeding 250°C (482°F). However, flammable atmospheres may form if contamination by light products (e.g., products created from cleaning or flushing lines) is disturbed. Ignition sources may include sparks, or static electricity. With this in mind, proper grounding is important along with the use of shielded electric motors.
- **Presence of toxic materials:** Fumes can be generated when asphalt is heated. These fumes contain particulate asphalt, hydrocarbon vapor, and sulfide gases. The latter is highly toxic and tends to build up in headspace. Proper venting is required to dispose of these fumes.

5.1.2 Recommended Storage and Handling Temperatures and Times

Asphalt and modified asphalt are stored and handled in similar ways. An exception is asphalt rubber, which is used shortly after manufacture. Allowable storage times are product specific and take into account the rate of property change, which occurs during storage. For example, an AR grade of conventional asphalt can be stored for several months, a PBA modified grade can be stored for several days, and asphalt rubber stored for only several hours.

5.2 ASPHALT EMULSIONS

Asphalt emulsions are a convenient way of handling asphalt. As water is the carrier of the asphalt and the system is chemically stabilized, emulsions may be subject to settlement or breaking prematurely. For this reason storage and handling are important issues. Over time emulsions will become coarser and undergo property changes, to avoid these problems timely use is often required. There are some simple rules for storage and handling of asphalt emulsions and they are discussed below.

5.2.1 Handling

Handling of emulsions is not difficult. By following the rules below potential problems can be avoided.

- **Pumping:** Pumps are a way of doing work on an emulsion. Pumps usually compress or shear the material they pump. This results in a compressed emulsion. If compression is too severe or occurs too often, the emulsion will become coarser by the mechanism of flocculation and coalescence and may revert back to straight asphalt. Pumps should be selected carefully. Diaphragm pumps are gentle, but require high maintenance and should only be used if essential. Centrifugal pumps are acceptable as long as the peripheral speed is not too high, less than 300rpm. Positive displacement pumps may be used, but usually 2-3 thousandths of an inch must be shimmed from the gears to provide adequate clearance and lastly old and worn pumps may be used. Always get expert advice on the appropriate pump to use.

- **Temperature:** When asphalt materials get cold, they shrink. In an emulsion, this means that the asphalt droplets get closer together. This has a number of important consequences. The material can flocculate and may coalesce; this may also cause the emulsion to settle out faster than desirable. If the material is pumped when cold the droplets are more compressed due to temperature related shrinkage. As a result, a pump that was not too tight in January may be far too tight in July. If the emulsion actually freezes, the droplets become frozen in contact and the emulsion will revert to bitumen upon thawing. For most emulsions, this happens if the emulsion gets to below 4°C (40°F). When materials get hot they expand. However, when water gets hot, its evaporation rate increases enormously. If the water evaporates, the droplets get closer together and can result in an emulsion reverting back to asphalt by the action of flocculation and coalescence. If any part of the emulsion gets hotter than 95°C (203°F) localized boiling may occur. If this happens, the droplets fuse back into asphalt. This fusing process raises a number of important aspects surrounding the heating process including the following:
 - When heating emulsions do it gently and heat according to specifications.
 - Use agitation while heating.
 - Warm pumps before use.
 - On bulk tanks in cold areas, the use of electrical heating is recommended.
 - Do not apply direct heat to emulsions with fire or a blowtorch.

5.2.2 Transport Handling

Emulsions are generally stable enough to transport. However, a common problem arises when air enters the emulsion. Air can cause the emulsion to break in the bubbles of air; CRS emulsions are particularly prone to break in this way. These larger particles can “seed” the emulsion causing settlement. Problems also arise when transport tanks are not clean. Mixing cationic and anionic emulsions can lead to breaking of the emulsion.

5.2.3 Storage

The points made for storing asphalt relate equally to the storage of an emulsion. When an emulsion is stored, it has a finite lifetime. This lifetime is determined by the formulation, handling and storage of the emulsion.

Asphalt is slightly heavier than water and as a result asphalt particles move to the bottom of the storage container. This movement is referred to as settling. If the particles pack in this way they can stick together (flocculate and coalesce) if this continues the emulsion will eventually turn back into bitumen. This settlement may be controlled to some extent by formulation. If the emulsion particles are fine enough to start with, they will settle more slowly allowing for longer storage life. Flocculation and coalescence can also occur as the result of electrical attraction between particles. If an emulsion is electrically unstable, it will flocculate and coalesce. This process may not take the emulsion entirely back to bitumen but the large particles formed as a result of this process will settle faster.

It is important to prevent settling by mixing an emulsion prior to the start of flocculation or coalescence. Once an emulsion has coarsened, remixing will not separate the larger particles again. If it has coarsened too much, pumping may break the emulsion. The only way to prevent problems is to start with a very fine emulsion and keep it properly maintained.

Tankage: While vertical tanks are preferred for plant storage, mobile storage is done with a road tanker. The road tanker increases the surface area of the emulsion exposed to air and can promote skinning. However, if properly handled, this will not become an issue for fieldwork. Specific guides for tankage include:

- Bulk tanks should be circulated at regular intervals. Circulation should be done slowly.
- The frequency of circulation will depend on the weather and how long the emulsion has spent in storage.
- Most emulsions only require circulation once a week in summer and once every five days during the winter.
- Circulation should be performed in the middle of the day, not first thing in the morning due to the colder temperatures.
- The time of circulation is based on the size of the tank; a 5000 Lt (1320 gal) tank should be circulated for 15 minutes while a 10,000 Lt (2640 gal) tank requires 20 minutes.
- Pumps must be flushed after use, but never into the emulsion tank.
- Lines and pumps should be able to be warmed before use.
- Lines should not be left part full of emulsion.

Table 3 shows the storage and application temperatures for emulsions currently in use by Caltrans (7, 15, 31).

Cleaning Procedures: For emulsions, cleanliness is very important. A sloppy operation will produce problems. When an emulsion comes in contact with air, it can begin to break. When a cationic emulsion comes into contact with metal, it can begin to break. Thus, if a pump is not properly cleaned after use, it will clog. If lines are left part full of emulsion, they will clog. The higher the performance of the emulsion, the more critical cleaning is. Cleaning should be done before storage of equipment and it should be done thoroughly. Specific guidelines include:

- Flush equipment including hoses thoroughly with WATER.
- Flush equipment and hoses with kerosene, NOT diesel, distillate or other solvent. These materials may dissolve asphalt but they are also incompatible with the emulsion and may cause the emulsion to break rather than flush it away. *NEVER FLUSH INTO THE EMULSION TANK.*
- Finish with a second flush with water.
- If a pump or line is already clogged with bitumen gentle heat may be applied at the blockage. Do not apply heat to the lines, as this will break the emulsion.
- Soak pumps with kerosene for an hour or more.
- Flush again with water after blockage is removed.

Rust, dirt, grass or other foreign material should be kept out of the emulsion. This is especially important when working with cationic emulsions as they can break by reacting with foreign materials.

Table 3: Mixing, Spraying and Storage Temperatures of Emulsions

PRODUCT	MIXING TEMPERATURE °C	SPRAYING TEMPERATURE °C	STORAGE TEMPERATURE °C
RS-1	N/A	20-60	20-60
RS-2	N/A	20-60	50-85
MS-1	10-70	20-70	20-60
MS-2	10-70	N/A	50-85
MS-2h	10-70	N/A	50-85
SS-1	10-70	10-60	10-60
SS-1h	10-70	10-60	10-60
CRS-1	N/A	20-60	10-60
CRS-2	N/A	50-85	50-85
CMS-2s	10-70	N/A	50-85
CMS-2	10-70	N/A	50-85
CMS-2h	10-70	N/A	50-85
CSS-1	10-70	20-60	10-60
CSS-1h	10-70	20-60	10-60
PMRS-2	N/A	50-85	50-85
PMRS-2h	N/A	50-85	50-85
PMCRS-2	N/A	50-85	50-85
PMCRS-2h	N/A	50-85	50-85
QS-1	10-40	N/A	10-60
QS-1h	10-40	N/A	10-60
CQS-1	10-40	N/A	10-60
CQS-1h	10-40	N/A	10-60
LMCQS-1h	10-40	N/A	10-60
MSE	10-40	N/A	10-60

The main transport requirements are to ensure that correct pumping is used, pumps should be warmed in cool climates. Clean tanks or a switch-load process should be followed. Switch loading is a process by which materials are transported in tanks that last carried a compatible material and therefore do not require the tank to be cleaned between material switching. Table 4 provides acceptable switch loading combinations. Always pump into clean tanks and always transport full containers.

Emulsions are chemical systems. In order to avoid contamination, they should never be mixed with other types of emulsions or with other chemicals.

Table 4: Acceptable Switch Load Combinations (7)

LAST PRODUCT IN TANK	PRODUCT TO BE LOADED			
	ASPHALT CEMENT	CUTBACK ASPHALT	CATIONIC EMULSION	ANIONIC EMULSION
Asphalt Cement	OK to Load	OK to Load	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Cutback Asphalt	Empty to No Measurable Quantity	OK to Load	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Cationic Emulsion	Empty to No Measurable Quantity	Empty to No Measurable Quantity	OK to Load	Empty to No Measurable Quantity
Anionic Emulsion	Empty to No Measurable Quantity	Empty to No Measurable Quantity	Empty to No Measurable Quantity	OK to Load
Crude Petroleum and Residual Fuel Oils	Empty to No Measurable Quantity	Empty to No Measurable Quantity	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Any Product Not Listed Above	Tank Must be Cleaned	Tank Must be Cleaned	Tank Must be Cleaned	Tank Must be Cleaned

5.3 STORAGE AND HANDLING OF AGGREGATES

Aggregates must be handled and stored in a manner that avoids contamination, minimizes degradation and avoids contamination (32). Specific guidelines are as follows:

- Stockpile areas should be clean and stable to avoid contamination from the surrounding area.
- Stockpiles should be on free draining grades to avoid moisture entrapment.
- Stockpiles should be separated for different aggregate sizes to prevent inter-mingling.
- Segregation or separation of a blended aggregate is the primary concern. Segregation occurs mostly with coarse aggregates but even slurry-combined aggregate may segregate in the stockpile or on handling if it gets too dry. Segregation may be avoided by avoiding stockpiling in a cone shape. Acceptable stockpile shapes are either horizontal or radial. Making each end dump load a separate pile, each adjacent to the next, makes horizontal stockpiles. Radial stockpiles are made with a radial stacker (32).
- Degradation of the aggregate creating fines can be avoided by handling the stockpile as little as possible. In chip seal or slurry surfacing applications, re-screening may be considered.

6.0 SAMPLING BINDERS AND AGGREGATES

The following is the standard sampling requirements for testing. In the case of emulsions, sampling is a significant issue. Samples must be sent immediately for testing to ensure they are representative of the material used in the field.

Emulsions, as has been discussed, change and coarsen with storage and handling. This may result in an emulsion that is out of specification when tested despite being in specification when sampled and used. This is especially true of high binder PMCRS-2 and 2h type materials.

6.1 GENERAL SAMPLING

The following guidelines should be followed for sampling materials (32):

- Samples of emulsion and binder shall be taken in conformance with the requirements in AASHTO T 40, "Sampling Bituminous Materials," and Section 8-01 and 8-02 of the Construction Manual and California Test Method 125.
- Observe safety procedures.
- Sample binders daily using new, clean, dry 1 L Cans with Screw Lids.
- Samples are normally taken from the application lance at the rear of the distributor. Drain off sufficient material through the nozzle to ensure removal of any material lodged there.
- Samples should be taken after one-third and not more than two-thirds of the load has been removed.
- Do not submerge sample containers in solvent or wipe containers with solvent saturated cloths. Use a clean, dry cloth, only immediately after sampling, to clean containers.
- Attach a Sample Identification Form (TL-0101) to each material sample in accordance with Section 8-01 of the Construction Manual and instructions printed on the TL-0101 booklet.
- Protect the TL-0101 against moisture and stains.
- Provide the e-mail address of the RE on the TL-0101.
- Emulsions have a shelf life. It is important that all samples be sent to the Transportation Laboratory daily.
- Aggregates should be sampled according to the contractual requirements.
- Samples of aggregate shall be taken according to Section 39-3.03 "Proportioning" of the Standard Specifications.
- Samples may be taken from a conveyor belt or sampling chute.
- Field samples must be taken from the stockpile. AASHTO T 2 and Section 39 3.03 of the Standard Specifications (9) describe the method.

6.2 GENERAL TESTING DETAILS

Send samples for testing to the Transportation Laboratory:

**Division of Materials Engineering and Testing Services
Flexible Pavement Materials Branch, MS #5
5900 Folsom Boulevard
Sacramento, California 95819-4612**

- Samples are not to be shipped C.O.D.
- Emulsion will be tested for compliance with Section 94, “Asphaltic Emulsions”, of the Standard Specifications (9).
- Aggregate samples should be tested for compliance with Section 39 “Asphalt Concrete” or Section 37 “Seal Coats” of the Standard Specifications (9) as appropriate.
- Test results are mailed to Resident Engineers. To expedite return of test results, test cards can be e-mailed to the Resident Engineers, if an e-mail address is provided on the TL-0101.

7.0 REFERENCES

1. Zaniewski, J.P., Mamlouk, M.S., “Preventative Maintenance Effectiveness- Preventative Maintenance Treatments”, FHWA Report FHWA-SA-96-027, 1996.
2. International Slurry Surfacing Association, “Slurry Seal” Brochure, 1998.
3. Holleran, G., “Pavement Design as a Tool for Innovation”, Bitumen Asia Singapore, 1996.
4. Washington State Department of Transportation, “WSDOT Pavement Guide, Volume 2”, February 1995.
5. Oliver, J., “Thin Bituminous Surfacing and Desirable Road User Performance”, Australian Road Research Board, Report ARR 325, 1999.
6. Puzinauskas, V.P., Harrigan, E.T., Leahy, R.B., “Current Refining Practices for Paving Asphalt Production”, Strategic Highway Research Program, 1990.
7. Asphalt Institute Manual MS-4, “The Asphalt Handbook”, 1989.
8. Kirk, O., “Encyclopedia of Chemical Technology Volume 3”, Third Edition, pp. 284-327, 1978.
9. California Department of Transportation, Standard Specifications, 1999.
10. Roberts, F.L., Kandahl, P.S., Brown, E.R., “Hot Mix Materials, Mixture Design and Construction”, 2nd Edition, NAPA Research and Education Foundation, Maryland, 1996.
11. LAW A MACTEC Company, “Binders Training Course”, Sacramento, California, May 2002.
12. Asphalt Institute Manual SP-1, “Binders Specification and Testing”, 1995.
13. Holleran, G., “Analysis of Emulsion Stability and Asphalt Compatibility”, Asphalt Emulsion Manufacturing Association, International Symposium on Asphalt Emulsion Technology, 1999.
14. Holleran, G., Reed, J.R., “Economic Uses of Asphalt Emulsions”, International Road Federation Conference, Toronto, Canada, 1996.
15. Holleran, G., Reed, J., “Asphalt Emulsions” Congreso Exjectivo Carraterras, Monterey, Mexico, 1998.

16. Holleran, G., Hicks, R.G., Reed, J.R., "Effect of Particle Size and Distribution on Slurry Surfacing Microsurfacing Performance", International Slurry Surfacing Association, International Conference Berlin, Germany, 2002.
17. French Society for Asphalt Emulsions, "Bitumen Emulsions", 2000.
18. Shell Bitumen United Kingdom, The Shell Bitumen Handbook, 1990.
19. Holleran, G., Van Kirk, J., Reed, J.R., "Polymer Modification of Bitumen for Life Extension", International Road Federation Conference, Paris, France, 2001.
20. Lu, X., Issacson, U., Eklund J., "Phase Separation of SBS Polymer Modified Bitumens", Journal of Materials in Civil Engineering, February 1999.
21. Maccarrone, S., Holleran, G., Gnanaseelan, G., "Properties of Modified Binder and Relationship to Mix and Pavement Performance", Journal, AAPT, Volume 64, 1995.
22. California Department of Transportation, "Standard Special Provision", SSP S 8 M-20, "Asphalt" Sacramento, California, 1999.
23. California Department of Transportation, "Standard Special Provision", SSP 39-450 "Rubberized Asphalt Concrete (Type D)", SSP 39-480 "Rubberized Asphalt Concrete (Type O)" Sacramento, California, 1999.
24. Cano, J., "Asphalt Rubber", Bitumen Asia, Singapore, 1997.
25. California Department of Transportation, "Standard Special Provision", SSP 39-403, "Asphalt Concrete (Type D-MB)." Sacramento, California, 1999.
26. California Department of Transportation, "Standard Special Provision", SSP 39-405 "Asphalt Concrete (Type G-MB)." Sacramento, California.
27. Bahai, H., Davies, R., "Role of Crumb Rubber Content and Type in Changing Critical Properties Of Asphalt Binders", Journal, AAPT Volume 64, 1995.
28. Holleran, G., Van Kirk, J., "Asphalt Rubber", Bitumen Asia, Singapore, 1998.
29. Australian Institute of Petroleum, "Safe Handling of Bitumen Products", 1993.
30. Asphalt Emulsion Manufacturers Association, 3rd Edition, "A Basic Asphalt Emulsion Manual", Annapolis, Maryland, 1998.
31. METS California Department of Transportation, "Paint (Tack) Coat Guidelines", Sacramento, California, 2002.
32. "Construction of Hot Mix Pavements", The Asphalt Institute Manual Series 22, 2nd Edition, 1998.